

## **EGR RECOVERY SYSTEM AND METHOD**

### **BACKGROUND OF THE INVENTION**

#### **Cross-reference to Related Applications:**

**[0001]** This application claims priority to Provisional Application Serial No. 60/518,648, filed November 12, 2003, the disclosure of which is incorporated by reference.

#### **Field of the Invention:**

**[0002]** This invention relates to the field of exhaust gas recirculation (EGR) recovery.

#### **Description of the Related Art:**

**[0003]** There are competing controls at work with an exhaust gas recirculation (EGR) equipped engine. One is trying to keep the brake specific oxides of nitrogen (BSNOx) levels at the emission standard while the other is trying to maintain a drivable vehicle. EGR may be provided to an intake air charge to damp combustion temperatures, thus reducing the amount of BSNOx that is being produced. EGR, however, replaces some of the air in the intake charge, promoting smoke generation if the air-to-fuel ratio falls too far. Large amounts of smoke can occur with EGR application when the driver wants to quickly accelerate the vehicle. Under these conditions EGR flow may be suspended briefly while fuel is added and the turbocharger is used to accelerate the vehicle. Higher levels of BSNOx emissions, however, are produced while the EGR flow is suspended.

**[0004]** The BSNOx emission standard is based on a 20 minute driving cycle and contains numerous quick accelerations. The overall engine calibration may be lowered in order to make up for the higher level of BSNOx produced during rapid

accelerations. Lowering the engine calibration continuously to make up for brief periods of higher BSNO<sub>x</sub>, however, hurts the steady state fuel economy.

### SUMMARY OF THE INVENTION

**[0005]** A primary object of the invention is to overcome the deficiencies of the related art described above by providing an EGR recovery system and method. The present invention achieves these objects and others by providing an EGR recovery system and method.

**[0006]** In several aspects, the invention may provide an EGR recovery system and method. In particular, in a first aspect, a method of EGR recovery may comprise the steps of calculating a transient volume of EGR sufficient to maintain NO<sub>x</sub> emitted by an engine below a predetermined level during a period of transient operation of said engine, supplying an actual volume of EGR during said period of transient operation, measuring said actual level of EGR during said period of transient operation, calculating an EGR deficit between said transient volume of EGR and said actual volume of EGR during said period of transient operation, integrating said EGR deficit over said period of transient operation to calculate a deficit volume of EGR, calculating a following steady-state volume of EGR sufficient to maintain NO<sub>x</sub> emitted by said engine of said engine below said predetermined level during a following period of substantially steady-state operation of said engine, and supplying said following steady-state volume of EGR plus said deficit volume of EGR during said following period of substantially steady-state operation of said engine.

**[0007]** In a second aspect, a system for EGR recovery may comprise means for calculating a transient volume of EGR sufficient to maintain NO<sub>x</sub> emitted by an

engine below a predetermined level during a period of transient operation of said engine, means for supplying an actual volume of EGR during said period of transient operation, means for measuring said actual level of EGR during said period of transient operation, means for calculating an EGR deficit between said transient volume of EGR and said actual volume of EGR during said period of transient operation, means for integrating said EGR deficit over said period of transient operation to calculate a deficit volume of EGR, means for calculating a following steady-state volume of EGR sufficient to maintain NO<sub>x</sub> emitted by said engine of said engine below said predetermined level during a following period of substantially steady-state operation of said engine, and means for supplying said following steady-state volume of EGR plus said deficit volume of EGR during said following period of substantially steady-state operation of said engine.

**[0008]** The above and other features and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with reference to the accompanying drawings.

#### **BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS**

**[0009]** The accompanying drawings, which are incorporated herein and form part of the specification, illustrate various embodiments of the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention. In the drawings, like reference numbers indicate identical or functionally similar elements. A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood

by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

**[0010]** Fig. 1 is a schematic diagram of a turbo-charged internal combustion engine for use with an embodiment of the invention; and

Fig. 2 is an EGR schedule according to a first embodiment of the invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

**[0011]** In Fig. 1 is shown a schematic diagram of a turbo-charged internal combustion engine 222 for use with an embodiment of the invention. Turbo-charged internal combustion engine 222 may include a plurality of cylinders 224, each having a combustion chamber 226 fed by a runner 228 of an intake manifold 230. A compressor 204 may provide pressurized intake air 202 to intake manifold 230. Compressor 204 may have an inlet 240 receiving low pressure air 202, which may be at ambient pressure, and an outlet 242 plumbed to intake manifold 230. Also plumbed to intake manifold 230 may be an outlet 232 of an exhaust gas recirculation (EGR) valve 234. An inlet 236 of EGR valve 234 may scavenge exhaust gases from an exhaust manifold 238 also connected to combustion chambers 226.

**[0012]** Since lowering the engine calibration continuously to make up for brief periods of higher brake specific oxides of nitrogen (BSNO<sub>x</sub>) may hurt the steady state fuel economy, it would be desirable if the engine calibration could be raised. It would further be desirable if, rather than lowering the overall engine calibration in order to make up for the higher level of BSNO<sub>x</sub> produced during rapid accelerations, the amount of EGR flow lost during the brief suspended periods of no EGR could be made up when EGR was resumed.

**[0013]** Periods of EGR valve 234 closures that are not related to vehicle accelerations such as engine braking or light load operation may be ignored. Otherwise, the amount of EGR lost during periods of EGR valve 234 closures may be completely recovered by flowing additional EGR during steady state operation as long as the engine 222 is in a condition to support additional EGR flow. Thus the overall engine calibration can remain at a higher BSNO<sub>x</sub> level without compromising fuel economy. Fuel economy is made worse only while the EGR flow is being recovered.

**[0014]** In particular, the difference between the desired EGR gas flow from the output of the exhaust gas demand module (EGDM) and the actual EGR flow evaluated from the gas flow measurement may be used to calculate a deficit. The deficit may be translated into a unitless parameter, which is summed up over time (integration). The integration may be frozen (stopped) for any combination of exhaust gas on/off (EGOO) control bits via a bit mask. The features of the EGR on/off may be reflected in any combination into the exhaust gas recirculation recovery (EGRR).

**[0015]** In addition, the EGRR may have a load threshold for freezing the integrator. The integrator value may be used to calculate the flow rate of EGR to be added to the normally calculated desired amount of EGR flow. This may be done over a programmable period of time. A higher flow rate for a shorter time period or a lower flow rate for a longer time period may be used. The longer time period may result in poorer fuel economy for a long time period. A short time period may result in more smoke during the recovery period.

**[0016]** The recovery time period for best fuel economy may be balanced against acceptable smoke and particulate emissions. The EGR recovery rate may ultimately be capped by the smoke limiter. If the EGR recovery places the air-to-fuel ratio too close to the smoke limit air-to-fuel ratio, the EGR recovery rate may be reduced to prevent smoke, extending the recovery time. If there is a poor operating range in the speed range of the engine, a multiplier may be set to reduce the additional input of EGR. The goal is to use the full amount of EGR flow from the recovery calculation. Operating conditions such as high altitude may limit the amount of recovery possible as well.

**[0017]** In particular, as shown graphically in Fig. 2, in a first embodiment a method of EGR recovery 300 may comprise the steps of calculating a transient volume of EGR 302 sufficient to maintain NO<sub>x</sub> emitted by an engine 222 below a predetermined level 308 during a period of transient operation 310 of engine 222, supplying an actual volume of EGR 312 during period of transient operation 310, measuring actual volume of EGR 312 during period of transient operation 310, calculating an EGR deficit 314 between transient volume of EGR 302 and actual volume of EGR 312 during period of transient operation 310, integrating EGR deficit 314 over period of transient operation 310 to calculate a deficit volume of EGR 316, calculating a following steady-state volume of EGR 318 sufficient to maintain NO<sub>x</sub> emitted by engine 222 of engine 222 below predetermined level 308 during a following period of substantially steady-state operation 320 of engine 222, supplying following steady-state volume of EGR 318 plus deficit volume of EGR 316 during following period of substantially steady-state operation 320 of engine 222.

**[0018]** In one embodiment, method of EGR recovery 300 may also include calculating a leading steady-state volume of EGR 322 sufficient to maintain NO<sub>x</sub> emitted by an engine 222 below predetermined level 308 during a leading period of substantially steady-state operation 324 of engine 222, supplying leading steady-state volume of EGR 322 during leading period of substantially steady-state operation 324 of engine 222.

**[0019]** In one embodiment, method of EGR recovery 300 may also include reducing actual volume of EGR 312 during period of transient operation 310. In one embodiment, method of EGR recovery 300 may also include normalizing EGR deficit 314 to produce a unitless parameter. In one embodiment, method of EGR recovery 300 may also include freezing integration of EGR deficit 314 over period of transient operation 310 via a bit mask. In one embodiment, method of EGR recovery 300 may also include freezing integration of EGR deficit 314 over period of transient operation 310 at a load threshold. In one embodiment, method of EGR recovery 300 may also include adjusting a duration 326 of following period of substantially steady-state operation 320 of engine 222. In one embodiment, method of EGR recovery 300 may also include reducing deficit volume of EGR 316 supplied during following period of substantially steady-state operation 320 of engine 222 if an air-to-fuel ratio 328 approaches a smoke limit air-to-fuel ratio 130. In several embodiments, period of transient operation 310 may occur during acceleration, deceleration, braking, engine braking, or lugging.

**[0020]** Example I: An example of an EGR recovery program for use with an embodiment of the invention is attached.

**[0021]** The foregoing has described the principles, embodiments, and modes of operation of the present invention. However, the invention should not be construed as being limited to the particular embodiments described above, as they should be regarded as being illustrative and not restrictive. It should be appreciated that variations may be made in those embodiments by those skilled in the art without departing from the scope of the present invention.

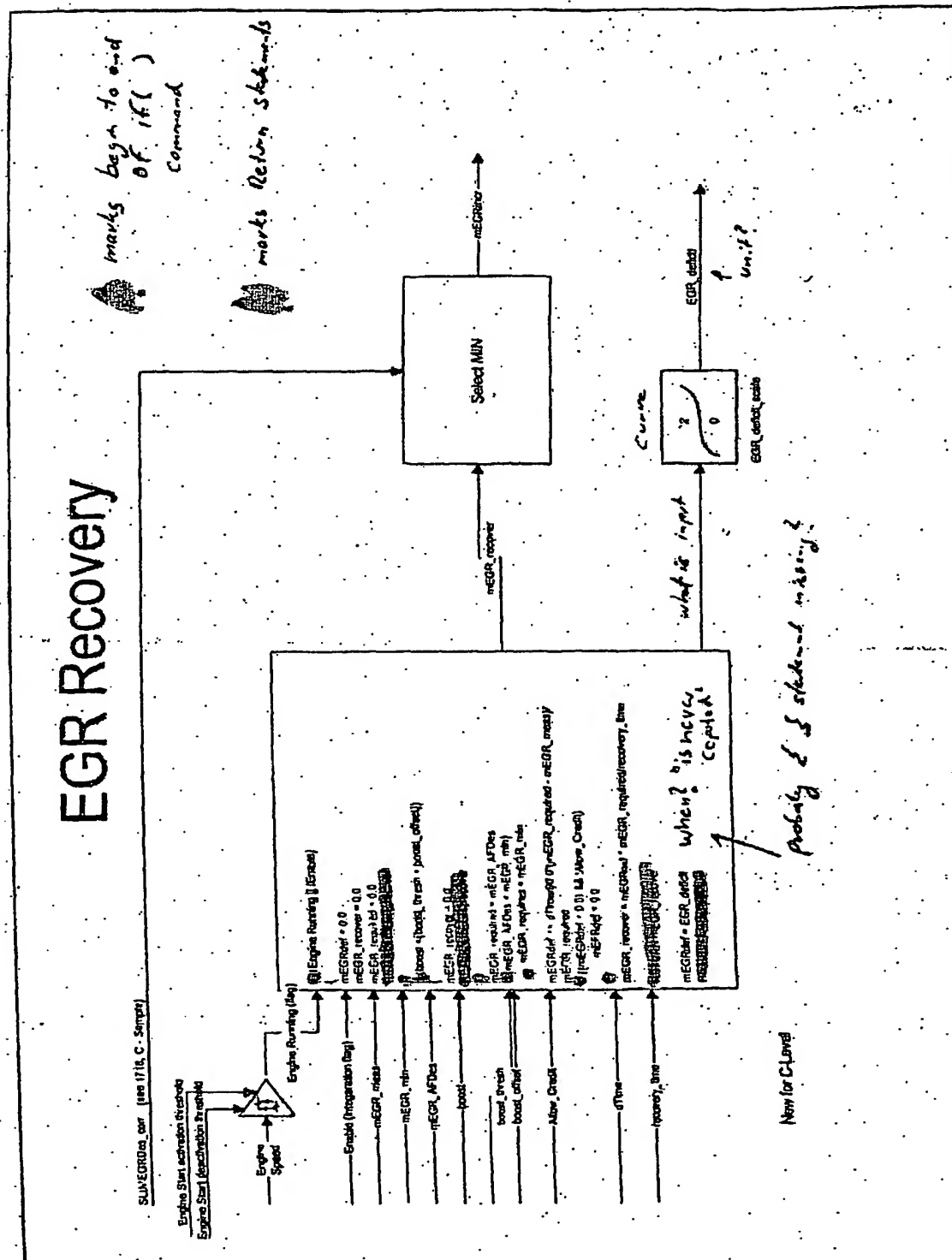
**[0022]** While the invention has been described in detail above, the invention is not intended to be limited to the specific embodiments as described. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concepts.

**[0023]** While various embodiments of the present invention have been described above, they should be understood to have been presented by way of examples only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by the above described embodiments.

**[0024]** Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that the invention may be practiced otherwise than as specifically described herein.



### EXAMPLE 1



## 6.8 EGR Recovery (EGRR)

### 6.8.1 Brief Description

The EGR Recovery is a function which calculates the differences between EGR gas flow desired (output from egdm) and the EGR gas flow measured "or evaluated by Gas Flow Model" (egfm). This difference, called deficit is translated to the time egrr\_dt\_egrdef\_l, which is added up into a buffer (integrator). The indication of this integrator shows the transient (static) behaviour of the EGR gas flow over time. From these value is build the egrr\_dm\_recover\_w and a like (derp) percent proportional factor egrr\_r\_deficit\_w.

### 6.8.2 EGR Recovery Overview Conditions

This function needs several conditions fulfilled for a proper work.

#### 6.8.2.1 The EGRR Enable Flag (egrr\_s\_enable\_b)

To get the EGR recovery function running this flag must be set. It can be enabled by setting EGRR\_S\_ENABLE\_B = TRUE and the engine running condition (egrr\_s\_running\_b) is true. In case of an disabled egrr (egrr\_s\_enable\_b = FALSE) the internal integrator egrr\_dt\_integrator\_l will be set to the initialisation value EGRR\_DT\_INIT\_CL. All outputs will follow to appropriate values.

NOTE: If the initialisation value is not zero, the output egrr\_dm\_recover\_w will follow to an egrr\_dm\_required\_w depend value (if there is no freeze condition active).

#### 6.8.2.2 The integrator freeze conditions

In case of at least one active flag egrr\_s\_illegal\_b, egrr\_s\_boost\_w or egrr\_s\_egoo\_b the egrr\_dt\_integrator\_l is hold on last valid value, the egrr\_dm\_required\_w is set to zero and also egrr\_dm\_recover\_w follows to zero.

##### The Illegal Flag (egrr\_s\_illegal\_b)

This is a security function to prevent a (application dependent) division by zero. This Flag is set (egrr\_s\_illegal\_b = TRUE) if the maximum selection's output becomes zero.

##### The Boost Flag (egrr\_s\_boost\_b)

This flag is set if the boost elaps\_p\_w is below the threshold, calculated in egdm\_p\_boostthresh\_w (with an offset EGRR\_P\_THROFSET\_CW). To prevent toggling states for values close to the threshold the hysteresis EGRR\_P\_HYST\_CW is added.

##### The Ego0 Flag (egrr\_s\_egoo\_b)

This flag is set if the bit wise negated egoo\_s\_case\_uw (egrr\_s\_egoocase\_uw) fits to the mask EGRR\_S\_EGOOMASK\_CUVW. The condition can be chosen either as bit wise AND (EGRR\_S\_ANDOR\_EGOO\_CB = 1) or as an simple OR with (EGRR\_S\_ANDOR\_EGOO\_CB = 0). To prevent toggling conditions there is integrated a Timer EGRR\_DT\_EGOO\_CUC (egrr\_dt\_egoo\_uc) for switch on (egrr\_s\_egoo\_b => TRUE) delay. This Timer can be disabled with setting to 0x00.

### 6.8.3 EGR Recovery Calculations

The function calculates the difference between egfm\_dm\_egroat\_w and egdm\_dm\_maxegfm\_w (limited to EGRR\_DM\_MIN\_CW). From this difference the fraction is build as follow:

$$\text{egrr\_dm\_required\_w} = \max(\text{egdm\_dm\_des\_w}, \text{EGDM\_DM\_MIN\_CW})$$

---


$$\text{egrr\_r\_egrdef\_w} = \frac{\text{egrr\_dm\_required\_w} - \text{egrr\_dm\_egrout\_w}}{\text{egrr\_dm\_required\_w}}$$

This value (egrr\_r\_egrdef\_w) is provided with the sample time fegr\_dt\_sample\_w (to egrr\_dt\_egrdef\_w) and finally added to the integrator buffer egrr\_dt\_integrator\_w. The indication of the integrator egrr\_dt\_integrator\_w is translated to egrr\_dt\_integrator\_w (10ms/bit). This is the base for all following calculations. The egrr\_dt\_integrator\_w is limited to EGRR\_DT\_MAXEGR\_CL and EGRR\_DT\_MINEGR\_CL.

#### 6.8.4 EGR Recover deficit (egrr\_r\_deficit\_w)

This value is calculated by means of the curve EGRR\_R\_DEFICIT\_CUR depend on egrr\_dt\_integrator\_w.

#### 6.8.5 EGR Recover (egrr\_dm\_recover\_w)

The egrr\_dm\_recover\_w is calculated depend on egrr\_dt\_integrator\_w, egrr\_dm\_required\_w and EGRR\_DT\_RECOVERY\_CW, by formula.

$$\text{6.8.6 egrr\_dm\_recover\_w} = \frac{\text{egrr\_dt\_integrator\_w} * \text{egrr\_dm\_required\_w}}{\text{EGRR\_DT\_RECOVERY\_CW}}$$

#### 6.8.7 EGR Recover (egrr\_dm\_recover\_w)

This value is the minimum between egrr\_dm\_recover\_w and slm\_dm\_egrdesccr\_w (scaled through the means of EGRR\_SF\_EXTIN\_CUR, depend on engine speed)

#### 6.8.8 EGRR Remote Control

There is an remote control for the egrr\_r\_deficit\_w available. If the appropriate flag in rmtc\_d\_sw\_sepo\_w is set, the output egrr\_r\_deficit\_w will follow the value on rmtc\_r\_egr\_w. The value egrr\_dm\_recover\_w will follow this proportional control due to the means of the 'Invers' curve EGRR\_DT\_INVERS\_CUR.

##### NOTE:

The value egrr\_dm\_recover\_w is still depend on egrr\_dm\_required\_w and EGRR\_DT\_RECOVERY\_W.

This "inverse remote control" will work only for positive values. The Integrator can't be set to negative values with remote control (exception if the grading in EGRR\_R\_DEFICIT\_CUR also changes). If this function should be disabled, please set all values in EGRR\_DT\_INVERS\_CUR to zero (the output will follow).

##### 6.8.8.1 Flags In Case of Remote Control

- egrr\_s\_enable\_b is set to TRUE
  - egrr\_s\_boost\_b is set to FALSE
  - egrr\_s\_running\_b is set to FALSE
  - egrr\_s\_illegal\_b is set to FALSE
  - egrr\_s\_egco\_b is set to FALSE
-

**INPUT VARIABLES:**

eess\_n\_avg\_w  
 slim\_dm\_descor\_w  
 fegr\_dt\_sample\_w  
 egdm\_dm\_egrout\_w  
 egdm\_dm\_maxegrlim\_w  
  
 ebps\_p\_w  
 egdm\_p\_boostthresh\_w  
 srt\_s\_uc  
 rmtc\_r\_egr\_w  
 rmtc\_d\_sw\_sep0\_ul  
 egoo\_s\_case\_uw

engine speed  
 calculated flow from slim  
 egr system sample time in very high resolution  
 calculated (evaluated) egr flow  
 desired EGR Mass Flow after maximum limitation to  
 EGDM\_DM\_MAXLIMIT\_CW  
 boost pressure  
 boost threshold calculated in egdm  
 engine start flag  
 remote control replacement value  
 remote control set point bit mask  
 EGR on/off controller reason

**INTERNAL VARIABLES:**

egrr\_dt\_egrdef\_l  
 egrr\_dt\_defunlim\_l  
 egrr\_dt\_integrator\_l

ratio with sample time  
 ratio with sample plus integrator value  
 ratio stored in integrator

egrr\_dm\_required\_w  
 egrr\_dm\_external\_w  
 egrr\_dm\_deficit\_w  
 egrr\_dt\_integrator\_w  
 egrr\_l\_egrdef\_w  
 egrr\_sf\_external\_w  
 egrr\_s\_egooocase\_uw  
 egrr\_dt\_egoo\_uc

copy of egdm or limited input  
 corrected input from external input (slim)  
 deficit after subtraction desired - actual flow  
 ratio stored in integrator re-scaled to short (10 ms/bit)  
 nameless value, result from division  
 scaling factor from curve calculation  
 bit wise negated egoo\_s\_case\_uw  
 delay timer for egrr\_s\_egoo\_b activation

egrr\_s\_running\_b  
 egrr\_s\_boost\_b  
 egrr\_s\_egoo\_b  
 egrr\_s\_illegal\_b

engine running flag  
 switch off condition boost below threshold  
 switch off condition EG00 controller with mask  
 set in case of division by zero (egr\_r\_dm\_required = 0)

**OUTPUT VARIABLES:**

egrr\_dm\_recover\_w  
 egrr\_r\_deficit\_w  
 egrr\_dm\_egrincor\_w  
 egrr\_s\_enable\_b

recovery egr mass flow  
 egr recovery depend proportional factor  
 minimum of egrr\_dm\_recover\_w or slim\_dm\_egrdescor\_w (soaled)  
 enable flag for egrr function

**DATA:**

EGRR\_DT\_MAXEGR\_CL  
 EGRR\_DT\_MINEGR\_CL  
 EGRR\_DT\_INIT\_CL  
 EGRR\_DT\_EG00\_CUG  
 EGRR\_DM\_MIN\_CW  
 EGRR\_DT\_RECOVERY\_CW  
 EGRR\_P\_THROFFSET\_CW  
 EGRR\_P\_HYST\_CW  
 EGRR\_S\_ENABLE\_CB  
 EGRR\_S\_EG00MASK\_CUW  
 EGRR\_S\_ANDOR\_EG00\_CB  
  
 EGRR\_R\_DEPICIT\_OUR  
 EGRR\_DT\_INVERS\_CUR

maximum limit for integrator  
 minimum limit for integrator  
 init value for integrator  
 delay timer for switch in egoo condition  
 minimum input limit for input egdm\_dm  
 recovery time  
 offset to boost pressure (egdm\_p\_boost..)  
 debouncing hysteresis  
 enable EGR Recovery flag  
 EG00 Bit mask for freeze the integrator  
 switch to choose between "AND" and "OR" mask condition for egoo  
 integrator freeze condition  
 translation curve from EGR Recovery (dm) to value like dorp\_r\_w  
 inverse curve for remote control use

---

EGRR\_SF\_EXTIN\_CUR      scaling for external dm in (SLIM)

LOCAL #DEFINES:

